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Evaluation of Acidic Soil Tolerance Indices in Maize (*Zea mays* L.) Varieties in Assosa, Ethiopia

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Abstract: *Maize is the first most productive among cereals in Ethiopia and used for human consumption expended in the numerous forms of diets. However, its production and productivity is strongly affected by soil acidity and the major constraint in the high rain fall maize production areas of the country like in Benishangul Gumuz Region. Thus, this experiment was conducted to identify varieties for tolerance to soil acidity selection indices for developing high yielding maize varieties under acidic soil conditions, and assess the effect of liming on maize grain yield at Assosa and Bambasi Districts during 2017 main cropping season. The experiment was arranged in split plot design with 3 replications, and limed and unlimed soils were used as the main plots and 21 maize varieties planted as the sub-plots. Stress tolerant index (STI), mean productivity (MP), geometric mean productivity (GMP) and yield stability index (YSI) were the most effective stress indices which were highly associated with the grain yield in both soil environments at both locations. RGYR, YSI, TOL and SSI recognized the stable genotypes with slight grain yield reduction; yet, they are not correlated with high yield and certain genotypes which had poor in yield prospective. The three genotypes namely, SPRH1, BH547 and BH661 with high grain yield under both environments were identified which are the most adapted at both locations. Therefore, these genotypes were recommended as acidic tolerant varieties for the maize growers to use at acid prone areas and also suggested for breeders to consider in the future stress breeding program.*

Keywords: *Indices; Maize genotypes, soil acidity and Yield..*

1. INTRODUCTION

Maize (*Zea mays* L., 2n=2x=20) is the third most prominent cereal crop globally after wheat and rice which inhabits an essential role in the world economy and ranks the second widely grown among cereals for human consumption after wheat, hence it is important towards achieving food security (Muli *et al*., 2016). It is a staple nutrition and as a source of income for smallholder farmers in Africa, critically for Ethiopia. Besides, it serves as raw materials for the food industry (Smale *et al*., 2013; Tekeu, 2015). By the coming 2050, its demand will be doubled worldwide especially in the developing countries including Ethiopia contributing invaluable role for food and feed (FAO, 2017).

In most areas, is used as the only food source while for others it is used as a mixture with other food grains. Maize can be grown in various agro ecological zones in an extended range of altitudes from 0 to 3800 m.a.s.l, under precipitation levels from 200 mm to 2000 mm (Ramirez *et al*, 2017). The mid-altitude sub-humid agro-ecology with altitude range of 1000 to 1800 m.a.s.l receiving average annual rainfall distribution from 1000 to1500 mm year^{-1} is the highest potential for maize production in the country.

However, various biotic and abiotic stresses constrain the production and productivity of maize globally. Soil acidity is the second major challenge next to drought worldwide which strongly affects the production and productivity of maize. At this time, more than 30% of the earth's total area and over 50% of potentially arable lands in the world are acidic (Malekzadeh *et al*., 2015).

Aluminum (Al) toxicity is the most growth and yield-limiting factor in acid soils, which affects about 40% of the arable lands and constrain 67% of the crop production on the total acid soil area in the world (Ermias *et al*., 2013). Excess of Al^{3+}, Mn^{2+}, and H^{+} in the soil with Ca^{2+}, Mg^{2+} and $PO4^{3+}$ deficiencies, reduce the root growth and affects the absorption of essential nutrients from the soil in maize (Krstic *et al*., 2012).

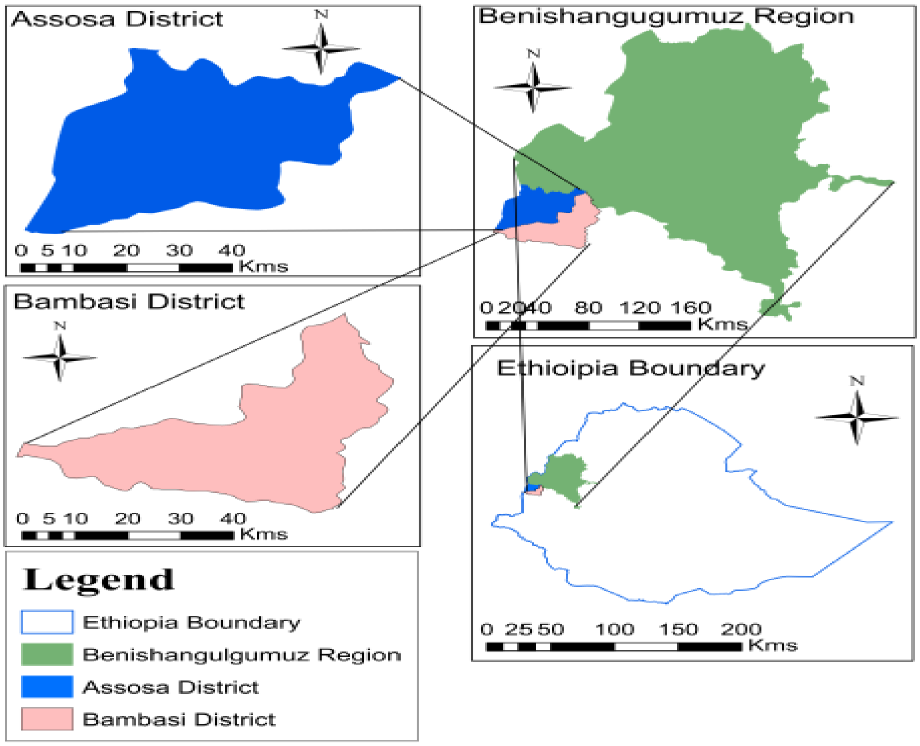
In Ethiopia, soil degradation is happening at an alarming rate and threatens maize production, especially acidic soil currently affects about 40% of the total arable land in the country and become stronger in the high-potential crop production zones (Taye, 2007). Vast areas of the country are strongly affected by soil acidity, posing a huge food security threat. The problem is more sever in the western, southern and central highlands of Ethiopia, where high intensity of soil leaching due to high temperatures and rainfall distributions are found (Mesfin, 2007; Adane, 2014 and Mekonen *et al.*, 2014).

Agriculture is the baseline livelihood source of managing their life in most areas of Benishangul Gumuz Regional State. Sorghum, maize, *tef*, finger millet, soybean, groundnut, haricot bean, sesame and niger seed are very common crops in the region. Yet in most parts of the region, strongly affected by soil fertility and acidity problem which are a major challenge for the production and productivity of maize, especially Bambasi and Assosa districts. Different suggestions are made to aggravate the problem in the areas, including, (i) high annual rainfall distribution causing soil nutrient leaching, especially macronutrients (ii) following continuous monocropping system, which leads crop mining, and (iii) deforestation affecting the disturbance and reduction of soil microorganisms. The food needed to sustain the people in the region comes largely from maize next to sorghum supported by the soil, but the problem increases the risk of production and productivity constraints (Daniel and Tefera, 2016). Improving the production and productivity of maize on acidic soil can be achieved either through the use of acidic soil (Al-toxicity) tolerant varieties or acid soil management practices such as liming. The national maize research program (NMRP) of Ethiopian Institute of Agricultural Research (EIAR) has released 60 (38 hybrids and 22 OPVs) improved maize varieties collaborating with different companions and stakeholders (MoANR, 2016). These varieties were developed and evaluated under non-acidic soil conditions and thus very little is known with regard to their reaction to acidic soil condition, especially those varieties released for mid and low land sub-humid agro-ecologies of Ethiopia. The two constituents for maize production improvement are the crop variety and soil management (Hefny, 2011). Therefore, the objectives of this study were to identify varieties for tolerance to soil acidity selection indices for developing high yielding maize varieties under acidic soil conditions, and assess the effect of liming on maize grain yield.

2. MATERIALS AND METHODS

2.1. Description of experimental sites

Assosa Agricultural Research Center (AsARC) is located about 680 km away from Addis Ababa in the North West direction in Benishangul Gumuz Regional State, 10°2ˈ24.19"N and 34°34ˈ19.16" E with the altitude range of 1541 to 1553 m.a.s.l. The area receives mean annual rainfall of 1165.97mm with the minimum and maximum temperature range of 14.9-27.97 ^{o}C with 5.02 soil pH found under strong acidic. Bambasi district (Amba 16 kebele) was also the second location which is situated 25 km far from Assosa town in the South West direction 9°56ˈ18.06"N and 34°39ˈ42.95"E at an altitude of 1440 m.a.s.l. The mean annual rainfall is about 1373.3mm with minimum and maximum temperature of 13.1-30.4 ^{o}C and 4.8 soil pH. Meteorological data were taken from Benishangul Gomez Region (Assosa Meteorological Service Center) which is located 3.5 km from Assosa Agricultural Research Center for both locations. Both testing sites have Unimodal rainfall pattern usually occurs from May to November. The dominant type of soil at both study sites is Nitosols with poor N and P nutrient availability. These two districts were selected as a study site because of their popularity for crop productivity, especially in maize which is extensively affected by soil acidity.



Source Google Map

Figure1. *Map of the study areas*

2.2. Experimental materials

Twenty one improved maize varieties which are suited for mid altitude sub humid agro-ecologies were used. Twelve hybrids and four OPVs were collected from Bako National Maize Research Coordinating center which was developed by the national maize research program of EIAR; five hybrids were developed and collected from private seed companies, four from Pioneer and one from Seedco (Table 1).

Table11. *Maize varieties used in the experiment*

S.N	Varieties	Pedigree	Variety type	Year of released	Owner	Maintainer
1	BH-140	SC22/ GuttoLMS	Hybrid	1988	EIAR	Bako NM
2	BH-660	A7033/F7215//142-1-e	Hybrid	1993	EIAR	Bako NM
3	BH-540	SC22/124b-109	Hybrid	1995	EIAR	Bako NM
4	BHQPY545	CML161/CML165	Hybrid	2008	CIMMYT	Bako NM
5	BH661	CML395/CML202//1142-1-e	Hybrid	2011	CIMMYT//EIAR	Bako NM
6	BH547	BKL002/CML312/BKL003	Hybrid	2013	EIAR	Bako NM
7	BH546	CML395/CML202//BKL001	Hybrid	2013	EIAR	Bako NM
8	SPRH1	-	Hybrid	2015	EIAR	Bako NM
9	SBRH1	-	Hybrid	2015	EIAR	Bako NM
10	BHQP548	-	Hybrid	2015	EIAR	Bako NM
11	BH670	A7033/F7215//1447b	Hybrid	2002	EIAR	Bako NM
12	BH543	SC22/124b(109)//CML197	Hybrid	2005	EIAR	Bako NM
13	PHB-3253 (Jabi)	-	Hybrid	1996	Pioneer	Pioneer
14	PHB-30G19 (Shone)	-	Hybrid	2006	Pioneer	Pioneer
15	P2859W (Shala)	-	Hybrid	2011	Pioneer	Pioneer
16	P3812W (Limu)	-	Hybrid	2012	Pioneer	Pioneer

17	Kuleni	OPV	OPV	1995	EIAR	Bako NM
18	Gibe-1	OPV	OPV	2001	EIAR	Bako NM
19	Gibe-2	ZM721	OPV	2011	EIAR	Bako NM
20	Gibe-3	OPV	OPV	2013	EIAR	Bako NM
21	SC627 (Abaraya)	-	Hybrid	2006	Seedco	Seedco

Source = From National Maize Research program (Bako)

2.3. Soil Sampling and analysis

Representative soil samples were collected from the rhizosphere for physicochemical characterization and determination of lime rate to be applied as per the method of Thiagalingam (2000). Before and after limed, subsoil samples were taken from 30 spots at the top (0-20 cm) soil depth diagonally in equal distance interval of each individual blocks using soil auger and mixed. Two components of soil samples before limed from the two locations (blocks) and two soil samples after harvesting from limed blocks of both locations totally four sample of 1kg of composite samples were prepared with appropriate labels in a plastic bags properly and sent for soil chemical laboratory analysis to investigate the lime effect and nutrient contents.

Soil pH value, cation exchange capacity (CEC), available phosphorous, total nitrogen (TN) and electron conductivity (EC) after harvesting were done at Addis Ababa National soil testing center, exchangeable bases (Ca, Mg, and Na and K) and micronutrients (Fe, Zn, Cu, Mn and B) were done at Horticoop (Horticultural) PLC in Addis Ababa Ethiopia whereas before planting soil analysis like bulk density, exchangeable acidity, and soil pH were ended at Assosa agricultural Research center.

Mehlich-3 multi-nutrient analysis method was used to estimates plant availability of macro micronutrients (Ca, Mg, Na, and K) and microelements (Fe, Zn, Cu, Mn and B) on soils from acid to neutral pH using a dilute acid-fluoride-EDTA solution of pH 2.5. Nitric and Acetic Acids were used to increase the solubility of Fe and Al- Phosphates and extracts a portion of Ca-phosphates. Fluoride serves to complex Al cations that potentially bind with P- thereby increasing the amount of Orthophosphate in the solution. Acetic Acid was used to keep the solution buffered below pH 2.9 to prevent Cal-Fluoride from precipitating. Ammonium exchanges with K, Ca and Mg and EDTA chelates, Fe, Mn, Zn, and Cu. Phosphorus and cations were determined by using inductively coupled plasma (ICP) spectrometer-AES instrumentation simultaneously. P-content in the solution was determined by spectral photo metrically at an acidity of 0.2M H_2SO_4 (Rodriguez *et al*., 1994).

Equipments used

During soil chemical analysis analytical balance, extraction bottles (PP and PE), 60ml, Erlenmeyer's flask (PP and PE), 100 ml, automatic solution dispenser, 20ml, reciprocating shaker, 200rpm, ICP-AES, filter funnels (PP and PE), scoop, 2g and Whatman #2 equivalent filter papers were used.

Chemicals used

Ammonium Nitrate (NH_4NO_3), fw = 80.05, CAS# 6484-52-2, Ammonium Fluoride (NH_4F), fw = 37.04, CAS# 12125-01-8, Nitric Acid (HNO_3), 68-70%, fw = 63.02, CAS# 7698-37-2, Ethylene diamine Tetra Acetic Acid (EDTA), $(HOOCCH_2)_2NCH_2CH_2N(CH_2COOH)_2$, fw = 292.25, CAS#60-00-4, Acetic Acid, Glacial (CH_3COOH), fw = 60.05, CAS# 64-19-7, Ammonium Fluoride - EDTA Stock Solution (3.75 M NH_4F - 0.25 M EDTA);Dissolve NH_4F in Demi water and EDTA, dissolve and dilute to 1000ml, and Mehlich-3 Extracting Solution (CH_3COOH + NH_4NO_3 + N NH_4F + HNO_3 + EDTA); Dissolve a known mass of NH_4NO_3 in about 3000ml of Demi water. Known volume of NH_4F+EDTAwas added in the standard solution and mixed well. Concentrated CH_3COOH and HNO_3 were also added and brought to final volume with the final pH 2.50±0.05.

2.4. Extraction procedures and analysis

Extraction-2.0 ± 0.05 g of air-dried soil were weighed that passed through a 10 mesh sieve (< 2.0 mm) in a 60ml plastic extraction bottles. The 20ml of Mehlich-3 extraction solution was added to the bottle and the Extraction flasks were placed on reciprocating mechanical shaker (200rpm) for five minutes. Suspension was filtered through a Whatman filter paper to a 100ml Erlenmeyer's flask.**Analysis**-the ICP apparatus was standardized using multiple element standards following manufacturer's approvals in the operation and calibration of the instrument. Dilution was made when a sample has concentrations above the highest standard. The pH was determined in 1:2.5 soil-water suspension using glass electrode (Jackson, 1973). Electrical conductivity was also determined from the saturation extract (1:5 soil-water ratios) of soils (Gupta, 2009). Total nitrogen was analyzed by the Kjeldhal method. Organic carbon (OC) and CEC were analyzed using mid-infrared diffused reflectance (MIR) spectral analysis.

2.5. Lime application rate

The amount of lime to be applied was determined based on the result of soil laboratory analysis and applied uniformly on the main plots. The lime rate per plot was determined and quantified based on the equation below using the exchangeable acidity, mass per 0.15m furrow slice and bulk density of the soil (Shoemaker *et al.*, 1961; Lierop, 1983; Hellmuth, 2016). The rate of lime applied was 2.82 and 3.6 t /ha, respectively at Assosa and Bambasi.

$$LR, CaCO_3\ (kg/ha) = \frac{cmolEA/kg\ of\ soil * 0.15\,m * 10^4\ m^2 * B.D.(Mg/m^3) * 1000}{2000}$$

Where LR = lime rate, EA = Exchangeable acidity, BD= Bulk Density

2.6. Experimental design and management

The experiment was laid out in split plot design with three replications. Limed and unlimed levels were considered as the main plots and 21 maize varieties as the sub-plots. The main and subplots were randomized independently. The main plot size was 5.1m x 33m (168.3m^2) while the subplot size was 1.5m x 5.1m (7.65m^2). The space between blocks, main plots and subplots were 2, 1.5 and 0.75 m, respectively. The space between rows was 0.75 m and 0.3m apart between plants within a row which is equivalent to planting density of 44,444 plants ha^{-1}. Two seeds were planted per hill and thinned two weeks after germination to one seedling per station.

Planting was done one month after limed when ample soil moisture reached an adequate level. Hence lime ($CaCO_3$) was applied at Assosa site in May 8/2017 and planting also done in June 8/2017. For the second site, Bambasi (Amba-16 kebele) lime was applied in May13/2017 and planted in June 13/2017. Two rows of a plot were used for data generation and harvesting whereas two rows used as a border at each edge of the block.

All other management practices such as Diamonium phosphate (DAP) and Urea were applied at the rate of 150 and 200kg ha^{-1} at both sites, respectively. The DAP was applied at planting time whereas urea was applied in split half at planting together with DAP and half two weeks after germination at thinning. Hand weeding was done three times at the 2nd, 4th and 6th weeks after seedling emergence.

2.7. Stress selection indices and measurement

After harvest, the data were collected from the grain yield under lime untreated plot (GYLUTP) and lime treated plot (GYLTP), then it was weighted in kilograms of ears from all plants per plot, and finally converted in to ton per hectare (t ha^{-1}). The experiment of acidic soil and lime treated soil considered as stressed and non-stressed environments respectively to estimate selection indices. For instance the GYLTP and GYLUTP respectively, represented the mean grain yield for each genotype under lime treated plot and the mean grain yield under lime untreated plot conditions, correspondingly also displayed the mean grain yield of all genotypes under lime treated plots (μGYLTP) and lime un treated (μGYLUTP) plots of soil environments. The subsequent stress indices were computed based on the seven measurements including: stress tolerance index (STI), stress susceptibility index (SSI), yield stability index (YSI), geometric mean productivity (GMP), mean productivity (MP), tolerance levels (TOL) and relative grain yield reduction (RGYR) of the genotypes for both soil conditions at both locations as shown in the table (Table 2).

Table22. *Soil acidity tolerance and susceptible indices*

Index	Formula	Reference
Stress Tolerance Index (STI)	$STI = \frac{(GYLTP)\qquad(GYLUTP)}{(\mu GYLTP)^2}$	Fernandez (1992)
Stress Susceptibility Index (SSI)	$SSI = \frac{GYLTP - GYLUTP}{YLTP * (1 - [\mu \frac{GYLUTP}{\mu GYLTP})}$	Fischer and Maurer (1978)
Stress Tolerance Level (TOL)	$TOL = GYLTP - GYLUTP$	Rosielle and Hamblin (1981)

Mean productivity (MP)	$MP = \frac{GYLTP + GYLUTP}{2}$	Rosielle and Hamblin (1981)
Yield Stability index	$YSI = \frac{GYLUTP}{GYLTP}$	Bouslama and Schapaugh (1984)
Geometric Mean Productivity (GMP)	$GMP = \sqrt{(GYLTP)(GYLUTP)}$	Fernández (1992)
Relative grain yield reduction (RYR)	$\mathbf{RGYR = 1 - \frac{GYLUTP}{GYLTP}}$	Blum (1988)

3. RESULTS AND DISCUSSION

3.1. Physiochemical characteristics of soil before and after lime application

In the soil chemical analysis, TN was varied from 0.16 to 0.17 % at Assosa and from 0.14 to 0.19% at Bambasi before and after limed in the soil. Hence TN was considered as the indicator of plant available N in the soil at both locations, critically at Bambasi. The C: N ratios for both Assosa and Bambasi were < 15 (Table 3). Taye *et al.* (2003) who reported that favorable C: N ratio is 15:1 to 30:1 due to N-needs are supplied with minimum oxidation of soil organic matter (SOM). The availability of OC also varied from 2.26 to 2.29 % at Assosa and from 1.89 to 2.11% at Bambasi which strongly affected the OM content in the soil. Alemu *et al.* (2016) who conveyed that narrow C: N ratios, advocate OM mineralization whereas wider C: N ratios indicate NO_3-immobilization by OM decomposing microorganisms. Magnesium deficiency problem was unfavorably observed at Assosa site because the exchangeable Ca: Mg ratio was greater than Bambasi site. Alemu *et al*. (2016) and Fanuel *et al*. (2017) reported that Mg deficiency occurs in soils with the high ratio of exchangeable Ca: Mg ratio (10:1). The value of EC was ranged from 0.062 to 0.082 ds/m for Assosa and 0.048 to 0.19 ds/m for Bambasi which signposts salt-free at both locations (Table 3).

The available P was found as the limiting factor for maize growth at both sites which varied from 0.91 to 1.47 Cmol (+)/kg at Assosa and 0.68 to 0.77 Cmol (+)/kg at Bambasi. Similarly, the availability of zinc (Zn) and boron (B) were also very low and no significant variation before and after liming at both sites with the amount of Zn was 0.01 Cmol (+)/kg at Assosa, and 0.01 to 0.02 Cmol (+)/kg at Bambasi whereas B, varied from 0.02 to 0.03 Cmol (+)/kg at both locations. The critical value of Zn for most Ethiopian soil is about 0.054 Cmol (+)/kg (EthioSIS, 2013). This finding revealed that the production of maize also strongly influenced by Zn and B deficiencies. According to EthioSIS (2014) soil map, available P, K, Na, Zn, and B were very low at both areas (Table 3).

Table33. *Soil chemical analysis, before and after lime applications in 2017 main cropping season*

Parameter	**Unit**	**Assosa**				**Bambasi**			
		Before LA	**Decision**	**After LA**	**Decision**	**Before LA**	**Decision**	**After LA**	**Decision**
P		0.91	Very low	1.47	Very low	0.68	Very low	0.77	Very low
K^+	**Cmol (+)/ kg**	0.10	Very low	0.12	Very low	0.10	Very low	0.10	Very low
Ca^{2+}		4.75	Low	17.54	Optimum	4.7	Low	9.73	Optimum
$(Mg^{2+}$		2.86	Optimum	2.9	Optimum	2.8	Optimum	2.89	Optimum
S		3.57	Optimum	4.36	Optimum	2.83	Optimum	4.71	Optimum
Na^+		0.24	Low	0.28	Low	0.25	Low	0.29	Low
Fe		8.02	Optimum	7.64	Optimum	8.07	Optimum	7.59	Optimum
Mn		4.64	High	4.61	High	7.24	High	6.6	High
Zn		0.01	Low	0.01	Low	0.01	Low	0.02	Low
B		0.02	Low	0.03	Low	0.02	Low	0.03	Low
Cu		0.12	Optimum	0.13	Optimum	0.14	Optimum	0.15	Optimum

CEC		19.3	Medium	25.5	Medium	20.15	Medium	21.11	Medim
Ex. Acid		2.86	Very high	0.42	Very low	3.24	Very high	0.32	Very low
pH		5.02	Strong acidic	5.9	M.acidic	4.8	Strong acidic	5.5	M.acidic
EC	ds/m	0.082	Too low	0.062	Too low	0.048	Too low	0.19	Too low
T.N	%	0.16	Medium	0.17	Medium	0.14	Medium	0.19	Medium
O.C	%	2.26	Low	2.29	Low	1.89	Very low	2.11	Low
C:N		14	Low	14	Low	11	Low	13	Low

The degree of decision used as low, very low, Optimum, Medium, High, Very high and strong for soil laboratory result were based on the comparison of EthioSIS, 2013 and 2014 data. M.acidic = moderately acidic, Ex.acidi = Exchangeable acidity, LA = Lime Application, O.C = Organic Carbon, EC = Exchangeable Carbon, T.N = Total Nitrogen, C/N = Carbon to Nitrogen Ratio, CEC = Cat ion Exchangeable Capacity.

3.2. The mean performance of genotype

The mean performances of genotypes under acidic and limed soil environments at Assosa and Bambasi locations are presented in table 4 and 5 respectively. Grain yield (t ha^{-1}) ranged from 1.25 to 2.48 under acidic and from 1.98 to 3.81 under limed soil conditions respectively. Similarly at Bambasi location the grain yield (t ha $^{-1}$) also ranged from 2.94 to 6.02 in acidic and from 5.9 to 8.8 under limed soil conditions respectively. The highest grain yield (t ha^{-1}) was recorded from genotype SPRH1 (2.48), BH547 (2.28), BH661 (1.99) and BH 546 (1.5) in acid soil condition. Similarly the maximum grain yield (t ha^{-1}) also recorded from genotype BH547 (3.81), BH661 (3.77), SPRH1 (3.5) and BH546 (2.87) in limed soil state at Assosa site (Table 4). Comparable grain yield (t ha^{-1}) result was also obtained from Bambasi location from the genotype SPRH1 (6.02), BH547 (5.87), BH546 (5.44) and BH661 (5.32) separately in acid soil situation and from genotype BH547 (8.83), SPRH1 (8.62), BH661 (8.54) and BH546 (7.78) in limed soil environment (Table5). Generally, genotype SPRH1 which was rated the first in acidic soil condition and second in no acidic condition had low (29%) yield reduction demonstrating the comparative reliability of the performance of this genotype over the two environments at both Assosa and Bambasi locations. While improved varieties BH-140 and BHQPY545 contributed the lowest grain yield under both acidic and lime treated soil environments. Representing its reasonably poor performance as compared to other varieties.

3.3. Stress susceptible index (SSI)

Stress susceptibility index (SSI) estimates the level of vulnerability or bargain in the grain yield of a genotype under stress condition. The negative result of this index is found on every occasion yield under stress is higher than yield under lime treated. Lower magnitude of SSI shows a little reduction of yield under stress as compared to yield and higher stability and vice versa. The genotype that indicated SSI less than one are more tolerant of stress conditions (Khan and Mohammad, 2016). The lowest SSI values was observed for genotype SPRH1 (0.72) at Assosa and for genotypes BH660 (0.69), BH546 (0.79) and SPRH1 (0.8) at Bambasi location with good grain yield under both soil environments in table (Table 4 and 5) respectively. Hence according to SSI, these genotypes were relatively less reduction in yield under acid stress condition and selection based on low SSI favors high yield under stress environment.

3.4. Stress tolerance index (STI)

Stress tolerance index (STI) is used to identify genotypes that have high yield under both stress and non-stress environment. (Fernandez (1992) stated that the larger the value of STI for a genotype under stress environment, the higher is its stress tolerance and yield potential. Therefore, those genotypes which had high STI estimates can be considered as the most tolerant to soil acidity stress. The highest tolerance levels in the experiments were observed for genotype SPRH1, BH547and BH661 while the lowest was BH-140 at both Assosa and Bambasi locations. The mean grain yield values were also recorded from these genotypes which have the highest stress tolerance index values as shown in table (Table 4 and 5). These genotypes were well adapted at both soil environments.

3.5. Tolerance index (TOL)

The level of tolerance index (TOL) is the difference of grain yield under non-stress and stress conditions (Rosielle and Hamblin (1981). Thus the higher value of TOL, the greater the yield reduction under stress and the higher the stress sensitivity of the genotype, the lower its stability and vice versa. From the study the genotype BH661was observed the highest TOL value at both Assosa and Bambasi locations. Javed *et al.* (2016) confirmed that the negative TOL value for a given genotype showed the higher grain yield under stress than non-stress conditions.

3.6. Mean productivity (MP)

Mean productivity is the average of genotype yield under non-stress and stress conditions, and its higher values indicate its higher yield potential under both environments (Rosielle and Hamblin 1981). Hence the genotypes were BH547 (3.04 and 7.35) and SPRH1 (3.0 and 7.32) at both Assosa and Bambasi locations respectively. These genotypes also give the highest grain yield under both soil environments at both locations. Selection with high MP led to high yield under both environments, with certain predisposition in the direction of high yield under non-stress condition. The lowest MP value was recorded for the genotype BH-140 (1.73 and 4.42) at both locations respectively with low grain yield. This finding is also in line with Krstic *et al.*(2012), the average grain yield in the non-acid soil was highly significant ($P < 0.01$) and greater than the average yield of the acid soil environments (3.19 t ha^{-1} *vs.* 1.58 t ha^{-1}).

3.7. Geometric mean productivity (GMP)

The geometric mean productivity (GMP) is comparable with STI and MP in perceptive genotypes and its higher values show higher crop tolerance under stress environment. The highest GMP was recorded from genotype BH547 (2.68 and 6.78), SPRH1 (2.66 and 6.78) and BH661 (2.49 and 6.23) both Assosa and Bambasi respectively as shown in table (Table 4 and 5). Similar genotypes were recognized by both GMP and MP show a little biased towards high yield under non-stress soil environment. These varieties provide the highest grain yield at both locations which shows those genotypes were well adapted under both soil environments while the remaining genotypes were only promising under non stressed soil condition.

Table44. *Mean grain yield both limed and unlimed soil with acidity indices at Assosa in 2017 main cropping season*

Variety	**GYLTP** (t ha^{-1})	**GYLUTP** (t ha^{-1})	**STI**	**SSI**	**YSI**	**GMP**	**MP**	**TOL**	**RGYR**
BH-140	2.215	1.249	0.38	1.07	0.564	1.378	1.73	0.97	0.44
BH-660	2.504	1.424	0.48	1.05	0.569	1.594	1.96	1.08	0.43
BH-540	2.372	1.391	0.45	1.01	0.586	1.524	1.88	0.98	0.41
BHQPY545	1.983	1.262	0.34	0.89	0.636	1.437	1.62	0.72	0.36
BH661	3.774	1.996	1.02	1.15	0.529	2.486	2.89	1.78	0.47
BH547	3.807	2.279	1.18	0.98	0.599	2.676	3.04	1.53	0.40
BH546	2.873	1.517	0.59	1.15	0.528	1.816	2.20	1.36	0.47
SPRH1	3.514	2.483	1.19	0.72	0.707	2.654	3.00	1.03	0.29
SBRH1	2.496	1.558	0.53	0.92	0.624	1.676	2.03	0.94	0.38
BHQP548	2.617	1.602	0.57	0.95	0.612	1.762	2.11	1.02	0.39
BH670	2.721	1.354	0.50	1.23	0.498	1.647	2.04	1.37	0.50
BH543	2.974	1.728	0.70	1.02	0.581	1.995	2.35	1.25	0.42
PHB-3253	2.564	1.498	0.52	1.02	0.584	1.675	2.03	1.07	0.42
PHB-30G19	3.091	1.618	0.68	1.16	0.524	1.975	2.35	1.47	0.48
P2859W	2.498	1.507	0.51	0.97	0.603	1.635	2.00	0.99	0.40
P3812W	2.553	1.694	0.59	0.82	0.663	1.763	2.12	0.86	0.34
Kuleni	2.626	1.661	0.59	0.90	0.632	1.789	2.14	0.97	0.37
Gibe-1	2.455	1.354	0.45	1.10	0.551	1.533	1.90	1.10	0.45
Gibe-2	2.367	1.477	0.47	0.92	0.624	1.572	1.92	0.89	0.38
Gibe-3	2.283	1.506	0.47	0.83	0.660	1.554	1.89	0.78	0.34
SC627	2.693	1.500	0.55	1.08	0.557	1.728	2.10	1.19	0.44
Mean	**2.713**	**1.603**	**0.62**	**0.99**	**0.593**	**1.825**	**2.18**	**1.12**	**0.41**

GYLTP = Grain yield from lime treated plot, GYLUTP = Grain yield from lime untreated plot, STI = Stress Tolerance Index, SSI = Stress Susceptible Index, YSI = Yield Stability Index, GMP = Geometric Mean Productivity, MP = Mean productivity, TOL = Tolerance level and RGYR = Relative Grain Yield Reduction.

Table5. *Mean grain yield both limed and unlimed soil with acidity indices at Bambasi in 2017 main cropping season*

Variety	**GYLTP** (t ha^{-1})	**GYLUTP** (t ha^{-1})	**STI**	**SSI**	**YSI**	**GMP**	**MP**	**TOL**	**RGYR**
BH-140	5.902	2.936	0.385	1.32	0.50	3.786	4.419	2.966	0.503
BH-660	6.936	5.109	0.787	0.69	0.74	5.499	6.022	1.827	0.263
BH-540	6.000	3.732	0.498	1.00	0.62	4.307	4.866	2.268	0.378
BHQPY545	5.765	4.104	0.526	0.76	0.71	4.425	4.934	1.661	0.288
BH661	8.537	5.306	1.007	1.00	0.62	6.232	6.921	3.231	0.378
BH547	8.825	5.866	1.150	0.88	0.66	6.780	7.346	2.958	0.335
BH546	7.783	5.436	0.940	0.79	0.70	6.079	6.610	2.347	0.302
SPRH1	8.624	6.015	1.153	0.80	0.70	6.778	7.320	2.609	0.303
SBRH1	6.662	4.300	0.637	0.93	0.65	4.931	5.481	2.362	0.355
BHQP548	6.015	3.320	0.444	1.18	0.55	4.084	4.668	2.695	0.448
BH670	6.334	4.127	0.581	0.92	0.65	4.599	5.231	2.207	0.348
BH543	5.967	3.729	0.495	0.99	0.62	4.307	4.848	2.238	0.375
PHB-3253	6.759	4.384	0.659	0.93	0.65	5.015	5.572	2.375	0.351
PHB-30G19	7.428	4.116	0.680	1.17	0.55	5.148	5.772	3.312	0.446
P2859W	6.160	3.715	0.509	1.05	0.60	4.371	4.937	2.445	0.397
P3812W	6.771	3.705	0.558	1.19	0.55	4.629	5.238	3.065	0.453
Kuleni	6.199	3.711	0.511	1.06	0.60	4.398	4.955	2.488	0.401
Gibe-1	6.013	3.002	0.401	1.32	0.50	3.873	4.507	3.011	0.501
Gibe-2	6.085	3.496	0.473	1.12	0.57	4.213	4.790	2.589	0.425
Gibe-3	6.024	3.904	0.523	0.93	0.65	4.434	4.964	2.120	0.352
SC627	6.084	3.726	0.504	1.02	0.61	4.353	4.905	2.358	0.388
Means	**6.71**	**4.18**	**0.64**	**1.01**	**0.62**	**4.869**	**5.443**	**2.530**	**0.38**

GYLTP = Grain yield from lime treated plot, GYLUTP = Grain yield from lime untreated plot, STI = Stress Tolerance Index, SSI = Stress Susceptible Index, YSI = Yield Stability Index, GMP = Geometric Mean Productivity, MP = Mean productivity, TOL = Tolerance level and RGYR = Relative Grain Yield Reduction.

In general, suitable genotypes for acidic, limed and both soil conditions were indomitable based on several selection indices since the purpose of tolerant genotypes based on a particular criterion is not consistent. At Assosa, the values of MP, GMP and STI were high, but TOL and SSI were low for SPRH1 under stressed soil condition comparing with other varieties which accounted 2.48 t ha^{-1} grain yield, but BH140 was highly influenced by the soil resulted in 1.25 t ha^{-1} grain yield. Hence, MP, GMP and STI identified four well adapted genotypes (SPRH1, BH547, BH661 and BH546) under both soil environments while other genotypes are favorable under non stressed soil condition at both locations. This result is comparable with the previous finding reported by Farshadfar *et al*. (2013) and stated that the high values of STI, MP, GMP, and YSI with low levels of TOL and SSI are the indicator of resistance under the stressed condition. Fernandez (1992) and Golbashy *et al*. (2010) also reported that, varieties having high STI, MP, GMP, and YSI values with low TOL and SSI index values are also good indicator of stress resistance in wheat.

3.8. Correlations between the mean grain yields and indices

To decide the most required acid soil tolerance measures, the correlation between, the grain yields under stressed, the grain yield under non stressed soil environment and indices of acid soil tolerance were computed and presented in table (Table 6). Pearson correlation coefficient analysis system was done between mean grain yields under acidic and non-acidic soils with indices for Assosa (below diagonal) and Bambasi (above diagonal). The correlation analysis was revealed that the existence of highly significant difference between limed and unlimed yield at both sites dedicated the genotype. The correlation at Assosa shown that the association of STI, MP and, GMP with the grain yield for both GYLTP and GYLUTP were highly significant ($P \leq 0.01$) and strong positive. The correlation coefficient between STI and GYLTP, STI and GYLUTP were (0.954 and 0.972), MP with GYLTP and GLUTP were (0.98 and 0.949), and GMP with GYLTP and GYLUTP (0.964 and 0.96), respectively (Table 6). The magnitude of these indices in both stressed and unstressed conditions have the eminent role to indicate the potential of tolerance to soil acidity and the possibility of selecting acidic tolerant variety. This finding also similar with Yagdi and Sozen (2009), and Anwar *et al*. (2011) who reported that, the presence of positive and significant associations between STI, MP and, GMP with grain yield and yield components under stressed and non-stressed conditions are the desirable criteria for selecting stress tolerance genotypes and responsible for high yielding variety.

The correlations between STI, MP, and GMP were highly significant and positive, but negative and non-significant with SSI whereas highly significant with TOL and large degree relation. The correlation coefficient values of STI with YSI, TOL, and SSI were (0.159, 0.603 and -0.145), MP with YSI, TOL, and SSI were (-0.065, 0.679 and -0.052), and GMP with YSI, TOL, and SSI were (0.124, 0.636 and -0.109), respectively (Table 6). Hassanzadeh *et al*. (2009) and Boussen *et al*. (2010) showed that low association between STI, GMP, and MP against YSI, TOL and SSI can be the best indicator at different response of stress in wheat. From this study SPRH1, BH547 and BH661 were selected due to high STI, GMP, and MP values whereas Gibe1, Gibe2, Gibe3, BH540, BH140, and BHQPY545 were highly affected by the stress and recorded as the low values of these indices at Assosa.

Similarly, the association of STI, MP, and GMP were highly significant and strong positive ($P \leq 0.01$) with GYLTP and GYLUTP at Bambasi (Table 6). The correlation coefficient values of STI with GYLTP and GYLUTP were (0.966 and 0.976), MP with GYLTP and GYLUTP were (0.975 and 0.969), and GMP with GYLTP and GYLUTP were (0.965 and 0.979), respectively. There was strong negative significant correlation between GYLUTP and SSI which implies the stress strongly influenced the yield. There was negative significant association between RGYR and GYLUTP (-0.745) which indicate that soil acidity highly reduced the grain yield. These variations indicate the probability selecting the stress tolerance variety among the tested genotypes. The presence of positive significant correlations in both stressed and unstressed conditions of grain yield between MP, GMP and STI and negative significant correlations with SSI makes selection reliable at high MP, GMP, and STI values for stress tolerance genotype (Golabadi *et al*., 2006; Gholipouri *et al*., 2009 and Anwar *et al*., 2011). Sio-Se Mardeh *et al*., (2006) also reported that when the value of TOL became larger, there is greater yield reduction under stressed condition which makes higher stress sensitivity for the genotype. Therefore when selection is taken depend on TOL value may result reduction of yield under finest soil conditions. Similarly, it was also observed that YSI was significantly and strong positively correlated with grain yield under acidic soil conditions.

Table6. *5Correlations between GYLTP, GYLUTP and stress indices on maize above diagonal for Bambasi and below diagonal for Assosa in 2017*

Characters	GYLTP	GYLUTP	STI	SSI	YSI	GMP	MP	TOL	RGYR
GYLTP		0.89**	0.97**	-0.36	0.37	0.96**	0.98**	0.42	-0.37
GLUTP	0.87**		0.98**	-0.74**	0.74**	0.98**	0.97**	-0.04	-0.75**
STI	0.95**	0.97**		-0.58**	0.58**	0.99**	0.99**	0.17	0.58**
SSI	0.15	-0.36	-0.15		-0.99**	-0.59**	-0.56**	0.69**	0.99**
YSI	-0.13	0.37	0.16	-0.99**		0.59**	0.56**	-0.69**	-0.99**
GMP	0.96**	0.96**	0.99**	-0.11	0.12		0.99**	0.17	-0.59**
MP	0.98**	0.95**	0.99**	-0.05	0.07	0.99**		0.21	-0.56**
TOL	0.81**	0.41	0.60**	0.69**	-	0.64**	0.68**		0.69**

					0.68**				
RGYR	0.13	-0.37	-0.16	0.99**	-1.0**	-0.12	-0.07	0.68**	

**, Indicates the level of significance at $p \leq 0.01$, probability level. GYLTP and GYUTP = grain yield lime treated and lime untreated plots respectively. STI= stress tolerance index, SSI= stress susceptibility index, YSI= yield stability index, GMP= geometric mean productivity, MP= mean productivity, TOL=tolerance index and RGYR=relative grain yield reduction.

4. CONCLUSIONS AND RECOMMENDATIONS

From this experiment soil acidity had a determinant effect on the grain yield of maize varieties. The indices values, STI, MP, and GMP at the genotypes of SPRH1, BH547 and BH661 were recognized as acidic soil tolerant genotypes. These genotypes recorded the highest yield under both acidic and non-acidic soil environments enactments. The reason that selecting that genotypes having high values of STI, MP, GMP and YSI as well as strong association with GYLTP and GYLUTP due to less affected by soil nutrient disturbance comparing other genotypes. The highest yield loss was observed from BH670 at Assosa and from BH140 and Gibe1 at Bambasi. These indices have been also better able to identify soil acidity tolerant genotypes and the association between these parameters and grain yield in limed and unlimed soil are suitable indexes for selecting acidic tolerant genotypes for maize.

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